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Butterfly valves - How to estimate cavitation level and related damage on existing locks and at the laboratory?

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Abstract: The butterfly valves (3.5m diameter) of the new lock of Lanaye (Albert canal Belgium) are subject to cavitation during the filling/emptying of the lock. On site measurements were realized to characterize the cavitation and to optimize valves operation in order to decrease the intensity and duration of cavitation. For comparison, measurements were realized in an existing lock with similar valves which also experience cavitation but without associated damage since 1960. The duration of cavitation is more or less the same for both locks, but the cavitation intensity is more important in Lanaye. To check the appearance of eventual damages, annual monitoring of the valves is realized. Small damage was observed but the link with cavitation is not obvious. In parallel, at the laboratory, the efficiency of aeration provided around the valve was tested for different configurations. The sound and vibrations due to cavitation are reduced when aeration is provided. Tests realized on a pipe coated with Aluminum indicated that the damage is mainly located downstream of the valve on the upper part of the pipe. These tests confirm that aeration is appropriate to reduce damage induced by cavitation.

Keywords: Cavitation, butterfly valves, lock, monitoring, hydrophone.

1. Introduction

Historically, in Belgium, the filling and emptying of many navigation locks are regulated by butterfly valves. When the lift at the lock is high, the risk of cavitation around the valves increases. Presence of cavitation has been detected around the butterfly valves of the new lock of Lanaye, which was inaugurated in November 2015 (drop 13.7 m, Albert canal in Belgium). It led to several studies on site and at the laboratory from the estimation of the cavitation level to the observation of the related damages and the proposal of valve aeration to protect it.

Before the opening of the new lock of Lanaye to navigation, on site measurements were realized to estimate the cavitation level around the valves during the filling/emptying of the lock. For comparison, similar measurements were realized at the lock of Ittre (drop of 13.3 m, Charleroi-Bruxelles canal in Belgium).

Different solutions were proposed to decrease the time of exposure to cavitation at each opening of the valve, but none successfully suppressed it completely. At the lock of Lanaye, the time of exposure can be reduced to 5 minutes for each opening of the valve, which corresponds to less than 400 hours/year/valve. Is it enough to reduce significantly the lifetime of the valve? Does it lead to significant damages? To answer these questions, it was decided to monitor the valves on site. Once a year, a specific monitoring is organized by divers or by foot when the lock chamber is empty for maintenance. The observations after 1.5 years of use are commented.

In parallel, the different stages of cavitation were reproduced at the laboratory for butterfly valves of 0.2 m and 0.15 m diameter. In each case, (1) the cavitation coefficient was calculated, (2) the noise (sound pressure) was measured with a hydrophone and (3) the vibrations were measured with an accelerometer. Different techniques were tested to observe the damages due to cavitation. An Aluminum sheet was placed in the pipe downstream the valve and the pits due to cavitation were detected with a microscope. The location of the damages observed at the laboratory provides guidance for the monitoring on site. Finally, the efficiency of an aeration of the valve to decrease the damages was studied on a scale model.

2. In situ measurements and monitoring

2.1. In situ measurements at the locks of Ittre and Lanaye

In situ measurements were realized at the new lock of Lanaye to estimate the cavitation level around the valves during the leveling. For comparison, identical measurements were realized at the lock of Ittre. This lock has a drop similar (13.3 m) to the lock of Lanaye (13.7 m). The filling and emptying system is different, but the valves are of the same type, butterfly valves (diameter of 3.5 m for Lanaye 4 and 3 m for Ittre).

It is not possible to have an absolute measurement of the cavitation level around the valve. Nevertheless, different indicators related to cavitation can be deduced from measurements and compared for different configurations.

Several non-dimensional coefficients are used to characterize the cavitation (Tullis 1993, Baran et al. 2007, Bleuler 1939). They express the ratio between the physical parameters that limit the cavitation (upstream or downstream pressure) and those that increase cavitation (the head loss and/or the velocity). Larger values of the non-dimensional coefficient correspond to lower cavitation. The non-dimensional cavitation coefficients C and σ used in the following are:

$$C = \frac{H_2 - H_{vap}}{\Delta H + v^2 / 2g} \quad (1)$$

$$\sigma = \frac{H_1 - H_{vap}}{\Delta H} \quad (2)$$

where H_1 and H_2 = absolute piezometric level upstream and downstream of the valve, respectively, (reference = center of the pipe), H_{vap} = vaporization pressure (at 20°C, $H_{vap} \approx 0.3$ mH₂O), $\Delta H = H_1 - H_2$ = difference in piezometric level across the valve and v = mean velocity in the pipe downstream of the valve. To measure the piezometric level H_1 and H_2 on site, pressure gauges were placed in the stop log recesses located upstream and downstream of the valve. The discharge and then the velocity in the culvert is deduced from the evolution of the water level measured in the lock chamber.

The evolution of the cavitation coefficient C (Eq.1) around the downstream valves during a symmetrical emptying is plotted in Figure 1 for the lock of Ittre (black line) and for the lock of Lanaye with 2 different opening operating procedures of the valves (grey lines). Procedure A is recommended from the design (linear opening in 9 min) and the procedure B is an alternative corresponding to a faster opening of the valve at the beginning (bi-linear opening, 40° in 1 min, 90° in 6 min). The dotted lines correspond to $C=1$ (intense cavitation level) and $C=2.5$ (early stage of cavitation) as defined by Bleuler (1939) and Kurkjian and Pratt (1974). For the lock of Ittre, the cavitation coefficient C is always >1 , but remains < 2.5 during 5 min. For the lock of Lanaye, the duration and intensity of cavitation are decreased for a faster opening (procedure B). As it doesn't influence badly the other dimensioning criterions (mainly the water slope in the lock chamber during the leveling), it was recommended to use procedure B instead of A (Savary et al., 2016). With this modification, the duration of cavitation for Lanaye and Ittre is similar, but the cavitation for the lock of Lanaye remains more intense.

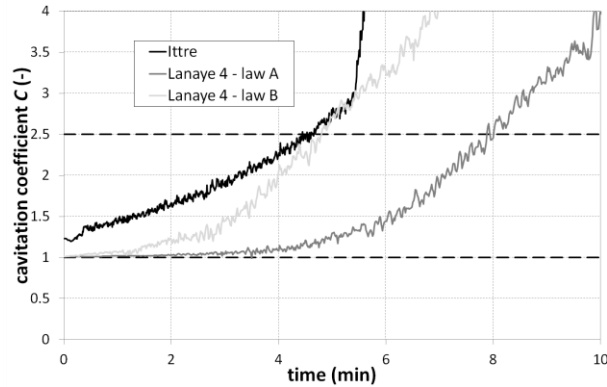


Figure 1. Evolution of the cavitation coefficient C during the emptying of the locks of Lanaye 4 and Ittre.

To have a more precise idea of the intensity of cavitation in both cases, the cavitation coefficient σ (eq.2) and the more detailed stages of cavitation as proposed by Tullis (1993) are plotted on Figure 3 for Ittre and on Figure 4 for Lanaye (opening B). The coefficients corresponding to the different stages of cavitation are specific for butterfly valves; they were determined on basis of experiments at the laboratory (Tullis 1993). In Figures 2 and 3, the coefficients were adapted to take scale effects (pressure and size) into account (Tullis 1993).

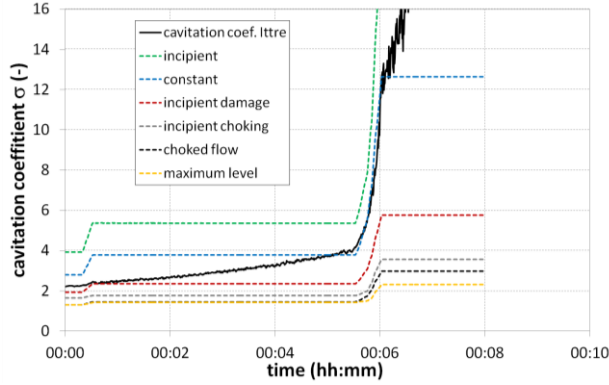


Figure 2. Evolution of the cavitation coefficient σ and limits during the emptying of the lock of Ittre

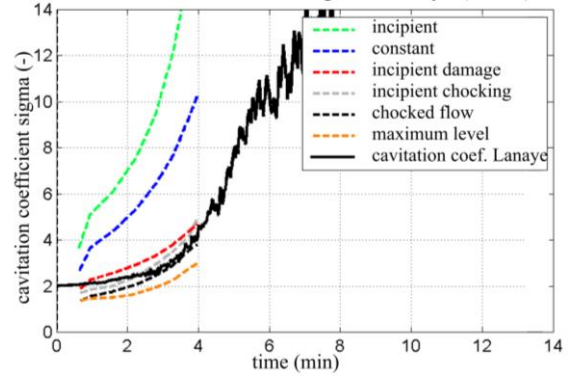


Figure 3. Evolution of the cavitation coefficient σ and limits during the emptying of the lock of Lanaye 4

According to figure 2, the cavitation at the lock of Ittre is light and doesn't induce damages (coefficient σ higher than the incipient damage limit). It is confirmed by the maintenance reports that reveal no preliminary wear of the valve or damages at the surrounding pipes since its opening to navigation in 1960. It confirms that the design criteria $C > 2.5$ proposed by Bleuler (1939) and used by the manufacturers of the valve is conservative. Contrary to the lock of Ittre, the cavitation level for the lock of Lanaye is strong enough to create damages (coefficient σ smaller than the incipient damage limit in figure 3). Consequently, no problem in the past at the lock of Ittre cannot lead to the conclusion that no problem will occur in the future at the lock of Lanaye.

Measurements of the noise and the vibrations induced by cavitation were realized with a hydrophone and an accelerometer. The analysis of those measurements led to the same conclusion than the analysis proposed here concerning the cavitation coefficients. The measurements set up and results detailed by Savary et al. (2016) and Savary and Libert (2015) for Lanaye and Savary and Libert (2013) for Ittre.

2.2. Monitoring of the damages at the lock of Lanaye

On the basis of 15 lockages per day, the limits corresponding to incipient damage cavitation is exceeded during more or less 400 hours/year if the valves are opened with procedure B. The procedure was optimized to reduce the duration of cavitation, but cavitation at an intense level is still present. It was decided to do annual monitoring of the valves and the culverts at proximity to check the evolution of the damages with time. When possible, we take advantage of the fact that the lock chamber is empty and dry for maintenance works to do the inspection. Otherwise, the inspection can be made by divers. The monitoring is realized according a basic structure, the location and information concerning the observed damages are collected.

The monitoring has been realized twice (2016 and 2017). In general, the degradations are not important. At some places, the protecting paint was removed and corrosion was observed. The damaged areas are mainly at the discontinuities like soldered joints in the culverts and at the periphery of the body of the valve (Figure 4, indicated in red), expansion waves and articulations. The border of the body of the valve, made of stainless steel is not damaged, ensuring good water tightness. Two areas located downstream of the valve in the upper part of the culvert are particularly damaged even if they don't present discontinuity (Figure 5). One of the valves is more degraded than the other despite the identical solicitation. It is assumed to be linked to the variation in the manufacturing or building conditions (e.g. painting adherence).

It is difficult to determine if the damages are linked to cavitation or are only due to the important velocity and abrasion due to the presence of sediments in the flow. Some of the damages are located upstream of the valve, at places which are not submitted to cavitation. Moreover, the damages don't present pitting patterns characteristics of cavitation. As

a comparison, an inspection of the butterfly valves of the new lock of Ivoz-Ramet was realized after one year of use. Due to the low drop of this lock (4.45 m), the butterfly valves (identical to those of Lanaye, same manufacturing) are not submitted to cavitation. Nevertheless, at some places the paint was also removed inducing corrosion. Nevertheless, the body of the valves seemed less damaged than the ones of Lanaye.



Figure 4. Global view from upstream of the downstream valve



Figure 5. Damages located downstream of the valve in the upper part of the culvert

No new damage appeared between 2016 and 2017, but the existing damaged areas enlarged. It was decided to maintain the rhythm of annual inspections.

3. Physical modeling

A physical model of a butterfly valve submitted to cavitation was built in the hydraulic research laboratory of SPW. The main purpose was (1) to reproduce the different stages of cavitation described in the literature (Tullis 1993 and Bleuler 1939), including the cavitation level observed at the lock of Lanaye and (2) to test the efficiency of aeration around the valve to reduce the damage due to cavitation.

3.1. Set up

As the cavitation occurs close to the valve, the physical model concerns only the butterfly valve and does not replicate the exact geometry of the culvert (Figure 6). In order to observe scale effects, 2 dimensions of valves were successively tested, diameter = 0.15 m and 0.2 m, respectively scale 1/23.3 and 1/17 regarding the valve of the lock of Lanaye. The pipe downstream of the valve is transparent, which facilitates flow and cavitation pockets observation.

The maximum pressure upstream is around 25 mH₂O (limited by the mechanical resistance of the transparent pipes) and the maximum discharge is around 200 l/s. The upstream pressure and discharge conditions can be modified by changing the rotation frequency of the pump or modifying valve opening at the upstream part of the model. The discharge is measured with an electromagnetic flow meter. The pressure upstream and downstream of the valve is measured with differential pressure gauges (position of the 4 pressure measurements on Figure 6). An accelerometer (Vibrasens138.01-6D-2, sensitivity 100 mV/g, maximum frequency 10 kHz) is placed on the pipe downstream of the valve to measure the vibrations in the 3 directions. A hydrophone (TC 4013 Teledyne Reson, maximum frequency 100 kHz) measures the sound pressure in water (Figure 7).

Specific inserts are located upstream and downstream of the valve in order to introduce air (Figure 8). The inserts are pierced of 92 holes of 1 mm diameter; the holes are connected to an air compressor (white tubing on Figure 8). The air is compressed at 2 bars and the air discharge is measured using an air flow meter. The air inlets are distributed in 4 areas, each one controlled by a valve so different configurations can be tested.

In order to reproduce the intensity of cavitation observed on the prototype in the physical model, the scale similarity is based on the conservation of the non-dimensional cavitation number (eq. 1 and 2). If the model was placed in a box where it would be possible to reduce the ambient pressure, it would be possible to conserve both the cavitation and the Froude number. Such installation is expensive and takes a lot of space. The facilities of the hydraulic research

laboratory of SPW do not offer this kind of installation. This implies that the Froude similarity between the scale model and the prototype is not respected. The Reynolds number Re is calculated for all the tested flow conditions on the prototype and on the scale model. On basis of the relative roughness of the pipe, the Moody diagram reveals that, the flow is always fully turbulent.

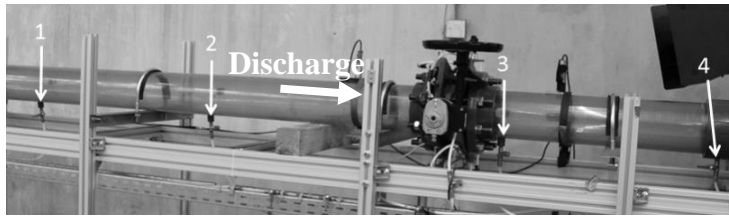


Figure 6. Set up (15 cm diameter)

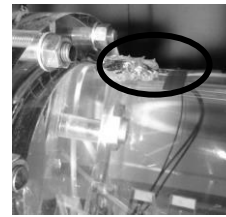


Figure 7. Hydrophone in the acoustic gel



Figure 8. Aeration system

3.2. Noise and vibration measurements

The hydrophone is located 10 cm downstream of the valve, outside the pipe, in acoustic gel to ensure a good sound transmission. The presence of the wall of the pipe between the hydrophone and the sound source (cavitation) affects the measurement. Nevertheless, as we are interested in comparison between different measurements realized in the same conditions and not in the absolute value of the measurement, it is not a problem (Bark & van Berlekom 1979). The influence of the position of the hydrophone is discussed below. The accelerometer is located 1 m downstream of the valve fastened on the upper part of the pipe.

As cavitation is a high frequency phenomenon, the noise level was recorded at the rate of 200 kHz and the vibration was recorded at the rate of 20480 Hz during 1s. Longer durations were tested (up to 5s) with the conclusion that the duration has no influence on the results. For each configuration, several recordings of the same flow conditions were realized to check the reproducibility of the measurement.

3.2.1. Stages of cavitation

The first step of the experimental campaign was to reproduce, for several openings of the valve, the different stages of cavitation (Tullis 1993) and to measure the noise level and the vibrations. Figures 9 to 11 are pictures of the flow downstream of the valve for different stages of cavitation (valve opening 53°). The position of the valve is illustrated in red at Figure 9.

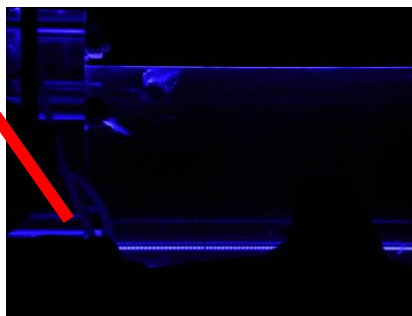


Figure 9. Constant cavitation

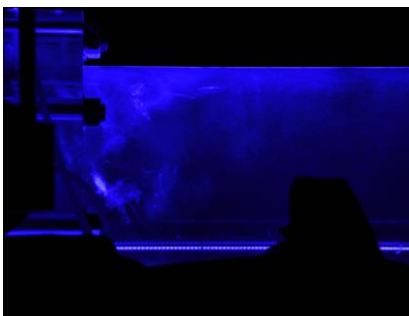


Figure 10. Incipient damage cavitation

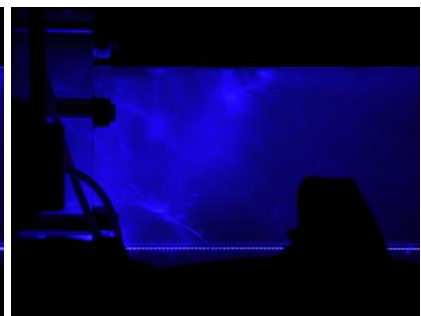


Figure 11. Intense cavitation

The spectrum expressing the variation of the sound pressure level (measurements from the hydrophone) with the frequency is pictured in Figure 12 for the different stages of cavitation. The spectrum obtained for the limit corresponding to incipient cavitation (earlier stage of cavitation) is close to the one obtained for a flow without cavitation. Then the power spectral density increases with the stage of cavitation. Regarding the not transformed signal, the amplitude and the root mean square value RMS (pink dots in Figure 15) increase with the cavitation level. A similar evolution of the vibration level with the increasing cavitation level is observed (pink dots in Figure 16).

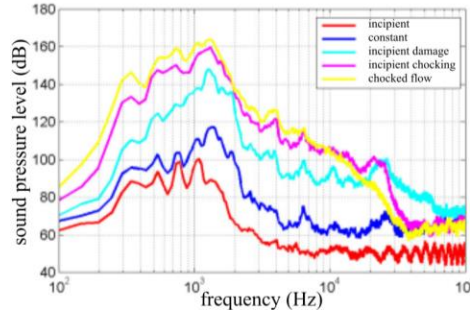


Figure 12. Sound pressure level measured for different stages of cavitation (valve opening 53°)

For a given level of cavitation (one colored curve at Figure 3), the intensity of the sound pressure level measured by the hydrophone does not vary a lot with the opening angle of the valve (Durvaux 2015). It confirms that the curves empirically proposed by Tullis (1993) fit to reality.

3.2.2. Efficiency of aeration to decrease cavitation damage

A specific aeration around the valve can decrease the effects of cavitation (Tullis 1989). Aeration does not increase the cavitation coefficient, but it creates an air mattress that protects surfaces from the impacts when the cavitation bubbles collapse. The efficiency of the aeration depends on the geometry of the air distribution. Different configurations were tested at the laboratory.

When aeration is provided, the noise decreases and the impacts of the collapsing bubbles of cavitation are not audible anymore. Figures 13 to 16 illustrate the effect of aeration on a flow submitted to intense cavitation. The sound pressure level (measured with the hydrophone) decreases when aeration is provided (Figures 13 and 15). For each stage of cavitation, the RMS of the sound pressure is plotted in Figure 15 with and without aeration. When the cavitation level is high (σ is small) (incipient damage, intense and very intense), aeration decreases the sound pressure. Aeration itself makes noise. For earlier stages of cavitation, when cavitation is intermittent, the noise of aeration is more dominant than the noise of the impacts due to cavitation.

The vibration level also decreases due to cavitation. Figure 14 presents the spectra deduced from the acceleration measurements (X direction, corresponding to the direction of the flow) for a flow submitted to intense cavitation with and without aeration. For most of the frequencies, the acceleration is decreased when the flow is aerated. The RMS value of the acceleration (X direction) is plotted in Figure 16 for the different stages of cavitation with and without aeration. For all the cavitation levels aeration decreases the intensity of vibration. The conclusions are the same for the acceleration in the 2 other directions (Y, Z)

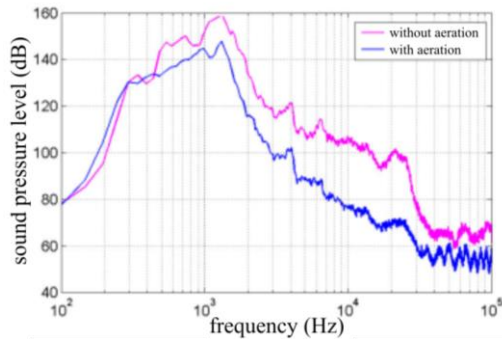


Figure 13. Sound pressure level measured (1) with (blue) and (2) without (pink) aeration for intense cavitation conditions

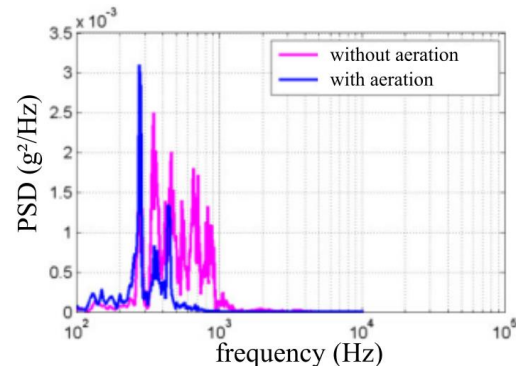


Figure 14. Power spectral density (acceleration) measured with (blue) and without (pink) cavitation for intense cavitation conditions

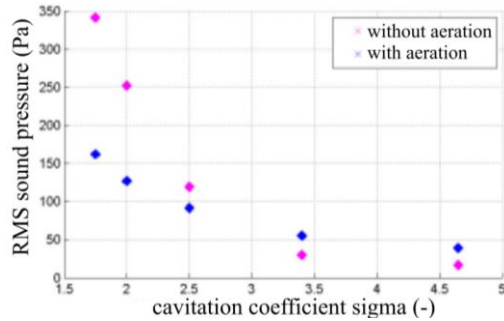


Figure 15. Root mean square value of the acoustic pressure with (blue) and (2) without (pink) aeration for different cavitation levels

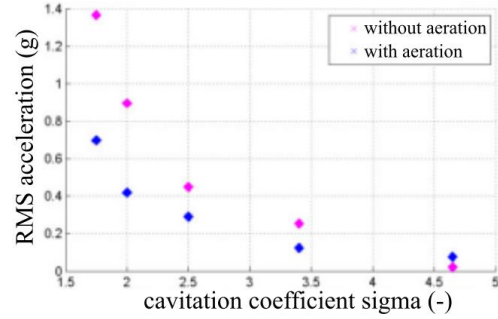


Figure 16. Root mean square value of the acceleration in X direction with (blue) and (2) without (pink) aeration for different cavitation levels

The measurements of Figures 12 to 16 were obtained using the insert for aeration located downstream of the valve. The air discharge was about 0.5% of the water discharge distributed on the perimeter. Different configurations of the aeration were tested:

- Location: aeration upstream, upstream and downstream, downstream of the valve;
- Repartition: 8 holes of 3mm diameter, 92 holes of 1mm diameter, distributed on the top, bottom, right side or left side of the pipe;
- Air discharge: from 0.5% to 4% of the water discharge.

All the tested configurations lead to the same noise and vibration reduction. Increasing the air discharge more than 0.5% of the water discharge is not necessary (Durvaux, 2015). The attenuation of the measured sound pressure due to aeration depends on the location of the hydrophone. Other tests were realized (1) with the hydrophone farther from the valve (50 cm downstream) and (2) with the hydrophone inside the pipe, 1 m downstream of the valve (Minet, 2017). The author also discussed scale effects by comparison of the results obtained at the lab for the valve of 15 and 20 cm diameter and the results obtained on site (3.5 m diameter).

3.3. Damages measurements

The measurements with the hydrophone and the accelerometer indicate that the aeration of the flow decreases the noise and the vibration due to cavitation. Extrapolated from these observations, it is supposed that aeration also decreases the number of impacts due to the collapse of the cavitation bubbles. Nevertheless, the flow (without cavitation) and the aeration itself also produce noise and vibration. It is sometimes difficult to determine which part of the measured noise or vibration is due to cavitation. Moreover, as mentioned above, measurements with the hydrophone and the accelerometer depend a lot on their position. For these reasons, and to have a better idea of the location of the damages, it was decided to observe the damages for different cavitating flow with and without aeration.

The visualization of the flow through the transparent pipe indicates that the cavitation pockets are located in a close neighboring (0 to 30 cm) downstream of the valve. A 35 cm length section of the pipe located downstream of the valve, corresponding to the area where the cavitation pockets were observed, was adapted. Different techniques were unsuccessfully tested:

- 8 Aluminum strips (length 35 cm, width 2 cm, thickness 1 mm) were screwed inside the pipe, distributed on the periphery (Figure 17). Aluminum (Al99.5%) was chosen because it can be easily deformed by the impacts due to cavitation (Tullis 1989). Problems occurred with the fixation of the strips, after several hours of tests some of them were removed by the flow (average velocities of 5 m/s). Moreover, some parts of the area of interest were not covered.
- The inside of the pipe was painted black (Figure 18). The idea was that the paint would be removed preferentially in areas subject to cavitation. For all the tested flow (intense cavitation with and without aeration), the paint on the upper part of the pipe was removed. At the opposite of expectations, no difference was noticed with or without aeration; the removal of the paint was probably linked to the high velocity of the flow and its trajectory. Another drawback was that the extension with time of the damaged area was variable and not reproducible (probably due to variation in the application of the paint).

- A pressure sensitive paper (Prescale paper distributed by FujiFilm) would be an ideal solution. It could indicate the location of the impacts and give information concerning the applied forces. We tested the “Low Pressure” paper (2.5 to 10 MPa), it is a compound of 2 sheets and the contact between the two sheets has to remain dry. Unfortunately, we didn’t manage to find a way to attach the sheets inside the pipe to resist to the flow velocity and to ensure water tightness. The paper for higher pressure range is mono- sheet, “Medium” pressure paper (10 to 50 MPa), like used by Nagaya et al. (2010) should be easier to place (no water tightness needed).

Finally, we decided to bend a sheet of Aluminum Al99.5% (length 35 cm, thickness 1mm) and to screw it inside of the pipe (Figure 19). Countersunk screws were used to avoid any intrusion in the flow that could induce local modification of the velocity.



Figure 17. Aluminum strips

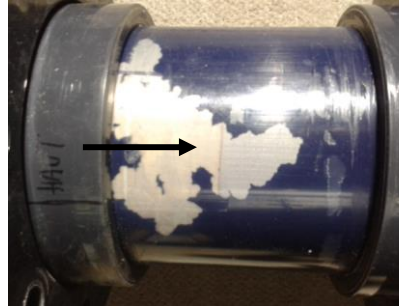


Figure 18. Black paint – view from above of the degraded area



Figure 19. Bended Aluminum sheet (with protection film on the upper part)

The tested configurations and the experimental conditions are listed in Table 1.

Table 1. Configurations for the tests

Test	Opening angle of the valve	Cavitation level	Aeration	Duration	Surface treatment
1	53°	Intense	No	60h	Not polished
2	53°	Intense	No	160h	Not polished
3	53°	Incipient damage	No	160h	Not polished
4	53°	Intense	Yes	160h	Not polished
5	53°	Intense	No	160h	Half polished
6	90°	No	No	160h	Not polished

After the experiment (60 to 160 h), the bent Aluminum sheet is cut in 8 pieces and a grid pattern (3 x 3 cm) is drawn. The surface is observed with a microscope with a magnification of 50x. For each square of the grid, one picture is recorded by the microscope. The selection of the picture recorded is done manually and is chosen to be representative of the area covered by the square.

The first test (Test 1 Table 1) was stopped after 60h, deep pits due to cavitation were observed, but the density was not important. It was decided to increase the duration of the tests to 160h for an easier analysis with the microscope. Figure 20 is the picture of the Aluminum sheet magnified by the microscope (2.5x1.9 mm in reality) in the most damaged area for intense cavitation (Test 2 in Table 1). Some of the deep pits are surrounded with red circles. The most damaged areas are located on the upper part of the pipe (+/- 30° from the upper generating line of the pipe) in the downstream neighboring of the valve (0 to 15 cm downstream of the valve). They are approximately delimited on Figure 21, the location corresponding to Figure 20 is also indicated by the red point.

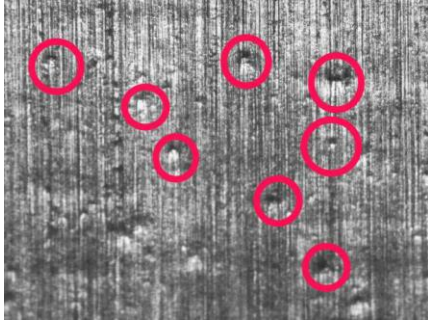


Figure 20. Pits due to cavitation – Test 2

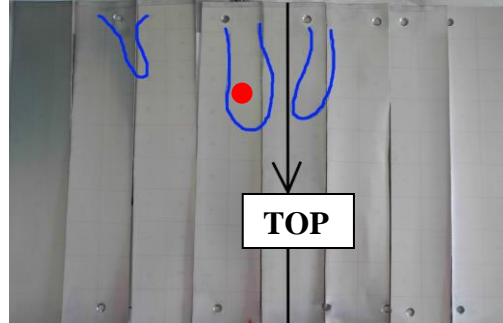


Figure 21. Most damaged areas – Test 2

In condition of intense cavitation, after 160h (Tests 2 and 5), in the most damaged area around 250 pits per cm² were manually counted. The results obtained for Tests 2 and 5 were similar, indicating a good reproducibility of the experiments. The only difference between the two tests was the initial surface treatment of the Aluminum sheet. For Test 5, half of the Aluminum sheet was manually polished in order to suppress the stripes due to the manufacturing visible at the microscope. Figure 22 is the equivalent of Figure 20 but for Test 5, with an initial polished surface. The damage is easier to detect when the surface is polished. In order to compare, Figures 23 and 24 are pictures of an area without cavitation, respectively, for polished and not polished Aluminum.

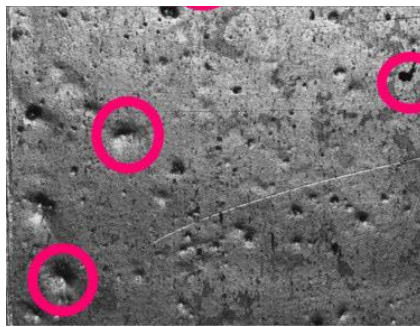


Figure 22. Pits due to cavitation – Test 5 – polished Aluminum

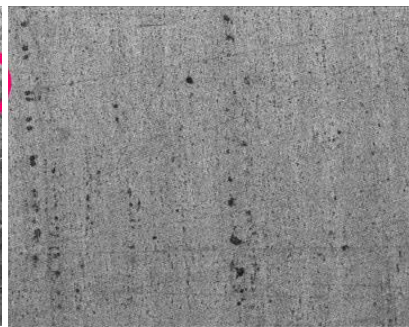


Figure 23. Not damaged areas – Test 5 – polished Aluminum

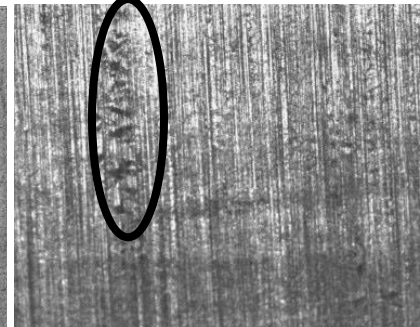


Figure 24. Not damaged areas – not polished Aluminum – Test 4 (equivalent to Tests 3 and 6)

Figure 24 corresponds to intense cavitation with aeration (the location of the pictured area is the same for Figures 20, 22 and 24). No deep pits are observed. The picture is the same than the one obtained for a flow without cavitation (Test 6). The marks like the one highlighted in Figure 24 are not due to cavitation; they are also present for a flow without cavitation. If the surface is polished before the test, these marks disappear. For Test 3, for an incipient damage level of cavitation, no pitting was observed on the Aluminum sheet downstream of the valve; Figure 24 is representative for all areas.

4. Conclusion

The opening procedure of the butterfly valves of the lock of Lanaye was modified (faster opening for angle < 40°) in order to decrease the duration of cavitation at each opening. Nevertheless, the valves are subjected to intense cavitation during 400 hr/year. Annual monitoring of the valves and the culverts are realized in order to estimate the implication in terms of damages. Right now, some small damages (removed paint and corrosion) were observed, but it is difficult to determine the part due to cavitation and the part due to the flow (high velocity and pressure fluctuation).

As an emergency plan, if it appears in the future that the damages due to cavitation become too important; an aeration system was studied at the laboratory. The cavitation conditions observed at the lock of Lanaye were reproduced with a scale model. Providing an aeration of 0.5% of the water discharge on the periphery of the valve decreases the damages. It was assumed from the noise and vibration measurements and confirmed with the observation of the damages induced to the pipe coated with Aluminum downstream of the valve. The experiments on the coated pipe

highlighted the location of critical areas. The damages are concentrated on the top of the pipe in the downstream neighboring of the valve, which corresponds to observations on site (Figure 5).

Unfortunately, the exact transposition to the lock of Lanaye of these results is not possible, because the similarity of the scale model is only based on the cavitation number and not on the Froude number. It was noticed that the pitting areas where cavitation pockets collapse can be deduced from the flow pattern. In the future, it could be interesting to reproduce the flow conditions corresponding to the lock of Lanaye on a scale model according the Froude similarity. Under these conditions, no cavitation will be observed on the scale model, but the flow trajectories could give indications concerning the precise location of the areas submitted to the collapse of the cavitation pockets.

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